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(54) Method of applying manipulations to a color digital image

(57) A method for modifying a digital image having color values with an extended color gamut comprising the steps of representing the extended color gamut digital image with a limited color gamut digital image and one or more associated residual image(s) representing a difference between the extended color gamut digital image and the limited color gamut digital image; specifying one or more desired image modification(s) to be applied to the extended color gamut digital image; and modifying the limited color gamut digital image and the residual image(s) to form a modified limited color gamut digital image and one or more modified residual image(s) in response to the specified desired image modification(s).

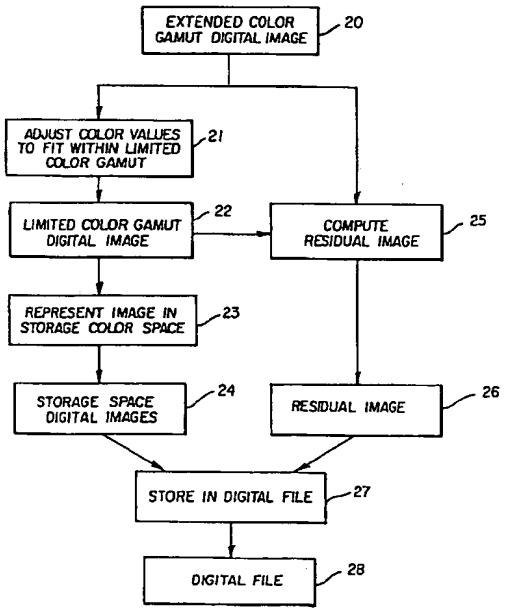

FIG. 2

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gamut and the color gamuts of other output devices and image sources represents a serious limitation on the usefulness of the video RGB color space. However, in many cases, the convenience of storing the image in a color space that is ready for direct display on a computer video CRT has been the over-riding factor in the determination of the preferred color space. This has come at the expense of applications that can utilize the extended color gamut information that can have existed in an input image. One of the most serious limitations of this approach involves cases where it is desired to modify the digital image. In this case, it is frequently beneficial to use the information that must be clipped off when representing the image in a video RGB color gamut to provide a better quality modified image. For example, if an image needs to be darkened due to the fact that the original image was over-exposed, the video RGB image will generally not retain the highlight detail information that could be used to darken the image.

[0011] It is an object of the present invention to overcome the limitations of the prior art by providing for the modification of digital images stored in a color space having a limited color gamut by retaining extended color gamut information.

[0012] This object is achieved in a method for modifying a digital image having color values with an extended color gamut comprising the steps of:

a) representing the extended color gamut digital image with a limited color gamut digital image and one or more associated residual image(s) representing a difference between the extended color gamut digital image and the limited color gamut digital image;

b) specifying one or more desired image modification(s) to be applied to the extended color gamut digital image; and

c) modifying the limited color gamut digital image and the residual image(s) to form a modified limited color gamut digital image and one or more modified residual image(s) in response to the specified desired image modification(s).

[0013] The present invention has the advantage that a digital image can be stored in a color space convenient for a particular application while overcoming the color gamut limitation associated with that color space.

[0014] It has the additional advantage that the use of the extended color gamut information is optional. As a result, the benefits of the extended color gamut information can be gained by applications that are able to make use of it, without introducing an image quality or computation penalty for applications that do not require the optional information or that are not able to make use of it.

[0015] It has the additional advantage that the extended color gamut information can be used to modify the image so as to provide a larger amount of adjustibility in the image modification process.

[0016] The image can be stored, for example, in a video RGB color space that is well-adapted for fast and convenient display on a computer system without compromising the potential quality of the image. This provides a particular advantage during the process of applying many types of modifications to the digital image.

FIG. 1 is graph comparing the color gamuts of a typical video display, and a typical reflection print;

FIG. 2 is a flowchart showing a process for making a limited gamut digital image in accordance with the present invention; and

FIG. 3 is a flowchart showing a second process for making a limited gamut digital image in accordance with the present invention;

FIG. 4 is a flowchart showing the reconstruction of a extended gamut digital image from the limited digital image of FIG. 2;

FIG. 5 is a flowchart showing the modification of the limited color gamut digital image and the residual image(s) in accordance with the present invention;

FIG. 6 is a flowchart showing the modification of the extended color gamut digital image in accordance with the present invention;

FIG. 7 is a flowchart showing the storing of information about desirable image modification(s) in accordance with the present invention.

[0017] One method for storing a digital image in accordance with the present invention is shown in FIG.2. An extended color gamut digital image 20 has color values that are outside the limited color gamut of a storage color space. An adjust color values step 21 is used to limit the color values to those that will fit within the limited color gamut of the storage color space to form a limited color gamut digital image 22. Next, a represent image in storage color space step 23 is used to produce a storage space digital image 24. A compute residual image(s) step 25 is used to determine one or more residual image(s) 26 representing the difference between the extended color gamut digital image and the limited color gamut digital image. The storage space digital image 24 and the residual image(s) 26 are then stored in a digital file 28 using a digital file storage step 27.

[0018] A key aspect of the present invention is the creation and use of the residual image(s) 26 representing the difference between the extended color gamut digital image and the limited color gamut digital image. Other prior art systems include the computation of a residual image, but none involve computing a difference between an extended color gamut digital image and a limited color gamut digital image. Nishihara et al. (U.S. Patent 4,903,317) describe the computation of a residual image determined from the difference between an original image, and an image that has been com-

preserve color appearance as closely as possible. Regardless of what gamut mapping technique is used, there will necessarily be a loss of information and a distortion of the color characteristics of the image.

[0025] In many cases, the extended color gamut will contain color values that have higher chroma values than can be represented in the limited color gamut. In some cases, the extended color gamut can also have a larger luminance dynamic range than can be represented in the limited color gamut. In the case where it is necessary to reduce the luminance dynamic range of the image, one part in the implementation of the adjust color values step 21 is typically the application of a tone scale function. The tone scale function maps the input image intensities to output image intensities and might be applied to a luminance channel of the image, or alternatively to each color channel of an RGB color representation. In some applications, the image being processed can actually be a monochrome image, e.g., a black-and-white image. In this case, the tonescale function can be applied to the monochrome image luminance values.

[0026] For cases where the extended color gamut digital image is a representation of the colors in an original scene, the adjust color values step 21 will typically involve determining reproduced color values that will produce desired aim colors on a target output device. For example, optimal color reproduction aims can be applied to determine desired video RGB aim colors for the original scene colors. The process of transforming the original scene color values into aim reproduced color values is sometimes referred to as "rendering" the image.

[0027] Once the limited color gamut digital image 22 has been determined, the next step is to represent it in the storage color space using the represent image in storage color space step 23. The output of this step is a storage space digital image 24. This step typically involves applying a device model, or a color space conversion, to determine the storage space color values that correspond to the adjusted color values of the limited color gamut digital image 22. For example, if the adjusted color values were specified in terms of the CIELAB color space, a video display device model can be used to determine the corresponding video RGB values that would be necessary to produce the specified adjusted color values.

[0028] A compute residual image(s) step 25 is used to determine one or more residual image(s) 26 representing the difference between the extended color gamut digital image 20 and the limited color gamut digital image 22. In its simplest form, a single residual image 26 can be calculated by simply subtracting the adjusted color values of the limited color gamut digital image 22 from the input color values of the extended color gamut digital image 20. The residual image would then be in terms of the color space used to represent those color values. Alternatively, the color values can be transformed into some other space that would be useful for computing the residual image. For example, it might be desirable to compute the residual image in a color space that is well-suited for compressing the residual image or that is convenient for use in reconstructing the extended color gamut digital image.

[0029] There are several reasons why it may be advantageous to store multiple residual images instead of just a single residual image. For example, it might be desirable to store residual errors associated with luminance errors in one residual image, and residual errors associated with chrominance errors in additional residual images. This would enable an application to make a choice about which types of residual errors it would use during the process of determining a reconstructed extended color gamut digital image.

[0030] In another case, a set of multiple residual images can correspond to different subsets of extended dynamic range image data. For example, a first residual image can extend the dynamic range of the digital image some fixed amount beyond the dynamic range associated with the limited color gamut digital image. A second residual image can then extend the dynamic range an additional increment beyond the extended dynamic range associated with the first residual image. In this way, an application using the extended color gamut digital image can use only the residual image(s) associated with the amount of extended dynamic range required by the application.

[0031] Another reason that using multiple residual images is useful is for cases where the residual images are stored in tags in the digital file having a limited size. In this case, the residual image data can be broken into smaller pieces that would fit within the size limitations. For example, residual images can be determined for subsets of pixels in the extended color gamut digital image. In this way, the residual image data can be stored in a tiled fashion.

[0032] Generally, the extended color gamut digital image and the limited color gamut digital image 22 should be represented in the same color space before the residual image(s) are calculated so that the in-gamut colors will be given by zero residual errors. Since most images will only have a small fraction of color values that are out of gamut, the residual image(s) will be dominated by zeros, and therefore will be highly compressible.

[0033] For the remainder of this disclosure, the case of a single residual image will be described. However, it should be recognized that the method can be easily generalized to use a set of multiple residual images.

[0034] For cases where the adjust color values step 21 involves the application of a transform that modifies the color values for the colors within the limited color gamut as well as those outside the limited color gamut, the residual image is determined by directly computing the difference between the input color values of the extended color gamut digital image and the adjusted

gamut digital image is generally well suited for display on a target output device such as a video display. One advantage of this approach is that systems that cannot make use of the residual image will be able to display and manipulate this image directly with no image quality or computation disadvantage relative to the prior art where only the limited color gamut digital image is stored. However, the information that normally would have been discarded has now been stored in the residual image and is available for use by systems that can utilize it. In this case, the limited color gamut digital image is extracted and the residual image from the digital file is used to form a reconstructed extended color gamut digital image.

[0039] FIG. 4 shows an example of reconstructing an extended color gamut digital image from the limited color gamut digital image and the residual image. The input to this process is an extended color gamut digital file 40 containing a limited color gamut digital image and a residual image created as described above. An extract data from digital file step 41 is used to extract the limited color gamut digital image 42 and the residual image 43. A reconstruct extended color gamut digital image step 44 is then used to form a reconstructed extended color gamut digital image 45 by combining the limited color gamut digital image 42 and the residual image 43. Typically the reconstruct extended color gamut digital image step 44 will involve combining the limited color gamut digital image 42 and the residual image 43.

[0040] The reconstructed extended color gamut digital image can be used for many different purposes. For example, it can be used to form a digital image appropriate for display on an output device having a color gamut different from the limited color gamut of the limited color gamut digital image 42 in the digital file 40. This enables the generation of an optimal print from the original extended color gamut digital image, rather than a print limited by constraints of the storage color space.

[0041] The information in the extended color gamut is particularly useful during the process of applying a modification to the digital image. Consider FIG. 5 which shows one method for modifying an extended color gamut digital image in accordance with the present invention. The input to this process is an extended color gamut digital file 40 containing a limited color gamut digital image and a residual image created as described above. As in FIG. 4, an extract data from digital file step 41 is used to extract the limited color gamut digital image 42 and the residual image 43. One or more desired image modification(s) 50 are then specified to be used to modify the image. The limited color gamut digital image 42 is then modified using a modify limited color gamut digital image step 51 in response to the desired image modification(s) 50 to form a modified limited color gamut digital image 53. Likewise, the residual image 43 is modified using a modify residual image step 52 in response to the desired image modification(s) 50 to form a modified residual image 54. The modified limited color gamut digital image 53 and the modified residual image 54 taken together represent a modified extended color gamut digital image which can be stored in a modified digital file 55. Alternatively, the modified digital image can be used to produce an image on a digital printer, or some other form of image display device. The modified digital image can also be transmitted to a remote location for storage or printing at that location. Methods for transmitting the modified digital image can include the use of a computer network connection, or a modem connected to a telephone line.

[0042] There are many different types of desired image modification(s) 50 that can be applied to the digital image. For example, there are many kinds of color and tone reproduction modifications that can be applied to an image. In some cases it will be desirable to adjust the color balance of the image. In other cases it will be desirable to adjust the density of the image so as to produce a darker image or a lighter image. Other types of color and tone reproduction modifications can include changes in the contrast, hue or colorfulness of the image. In some cases, it will also be desirable to modify the color and tone reproduction characteristics to optimize them for a specific output device. The present invention is particularly well-suited to making modifications to the color and tone reproduction characteristics of the image due to the fact that the extended color gamut information stored in the residual image will enable larger changes to be made without any degradation in quality. For example, consider the case where an original image is determined to be over-exposed. In this case, highlight information in the limited color gamut digital image would have been clipped off during the process of rendering the image to the limited color gamut. However, this highlight information would be retained in the residual image. If it were desired to darken the image to correct for the over-exposure error, the information in the residual can then be used to determine a modified digital image that recovers the highlight detail.

[0043] Other types of image modifications that can be applied to a digital image include spatial image modifications. Examples of spatial image modifications include zooming, cropping, noise reduction, and sharpening the image. Zooming an image involves a resizing of the image. Cropping an image involves selecting a subset of an image. A noise reduction process generally involves reducing the appearance of image grain or noise by smoothing the image in flat areas of the image. Sharpening an image typically involves applying a spatial convolution to the image to increase the apparent sharpness of edges in the image. There are many other types of image modifications such as those found in common image editing software programs such as the widely used Adobe PhotoShop.

[0044] In some cases a single image modification could be desired, whereas in other cases, it may be

or machine readable bar code; solid state electronic storage devices such as random access memory (RAM), or read only memory (ROM); or any other physical device or medium employed to store a computer program.

PARTS LIST

[0051]

10	video RGB color gamut
12	reflection print color gamut
20	extended color gamut digital image
21	adjust color values
22	limited color gamut digital image
23	represent image in storage color space
24	storage space digital image
25	compute residual image
26	residual image
27	digital file storage
28	digital file
30	extended color gamut digital image
31	adjust color values
32	represent image in storage color space
33	limited color gamut digital image
34	represent image in extended storage color space
35	compute residual image
36	residual image
37	digital file storage
38	digital file
40	digital file
41	extract data from digital file
42	limited color gamut digital image
43	residual image
44	reconstruct extended color gamut digital image
45	reconstructed extended color gamut digital image
50	desired image modification(s)
51	modify limited color gamut digital image
52	modify residual image
53	modified limited color gamut digital image
54	modified residual image
55	modified digital file
60	modify extended color gamut digital image
61	desired image modification(s)
62	modified extended color gamut digital image
63	modified limited color gamut digital image
64	modified residual image
65	modified digital file
70	desired image modification(s)
71	modify limited color gamut digital image
72	modified limited color gamut digital image
73	preview modified image
74	information about modification(s)
75	modified digital file

Claims

1. A method for representing a digital image with an extended color gamut in a storage color space having a limited color gamut comprising the steps of:

   a) adjusting the color values of the extended color gamut digital image to fit within the limited color gamut to form a limited color gamut digital image;
   b) representing the limited color gamut digital image in the storage color space;
   c) determining one of more residual images representing differences between the extended color gamut digital image and the limited color gamut digital image; and
   d) associating the one of or more residual image(s) with the limited color gamut digital image in the storage color space such that the associated set of residual images and the limited color gamut digital image is adapted to be used to form a reconstructed extended color gamut digital image.

2. The method of claim 1 further including the step of using one or more residual images from the set of residual images together with the limited color gamut digital image to form a reconstructed extended color gamut digital image.

3. A method for representing a digital image having color values with an extended color gamut in a storage color space having a limited color gamut comprising the steps of:

   a) adjusting the color values of the extended color gamut digital image to fit within the limited color gamut to form a limited color gamut digital image;
   b) representing the limited color gamut digital image in the storage color space;
   c) compressing the limited color gamut digital image;
   d) determining a set of residual images representing a difference between the extended color gamut digital image and an uncompressed version of the compressed limited color gamut digital image; and
   e) associating the set of residual images with the limited color gamut digital image in the storage color space such that the associated residual images and the limited color gamut digital image is adapted to be used to form a reconstructed extended color gamut digital image.

4. A method for modifying a digital image having color values with an extended color gamut comprising the steps of:

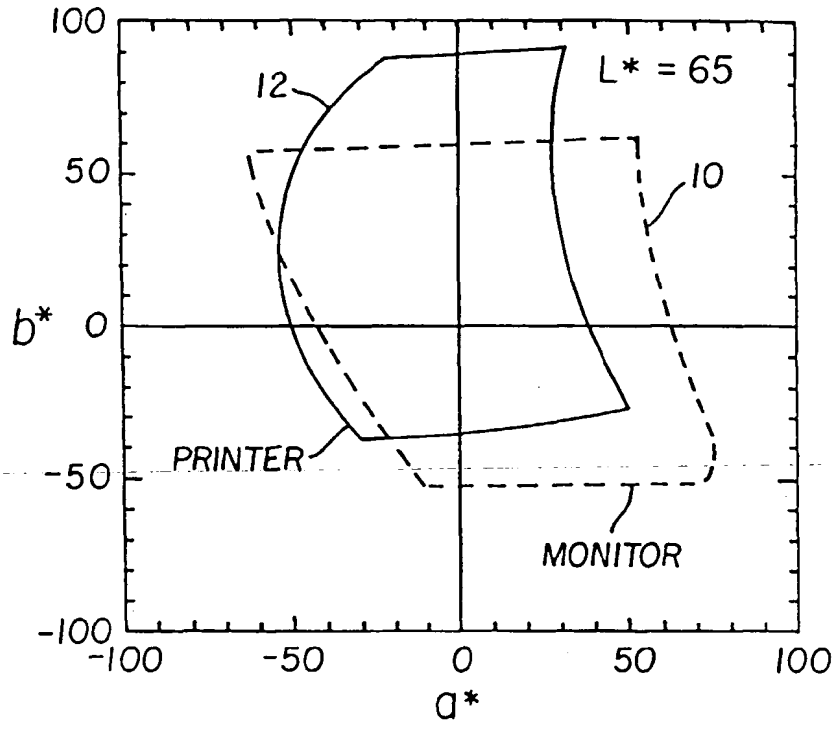

FIG. 1
(Prior Art)

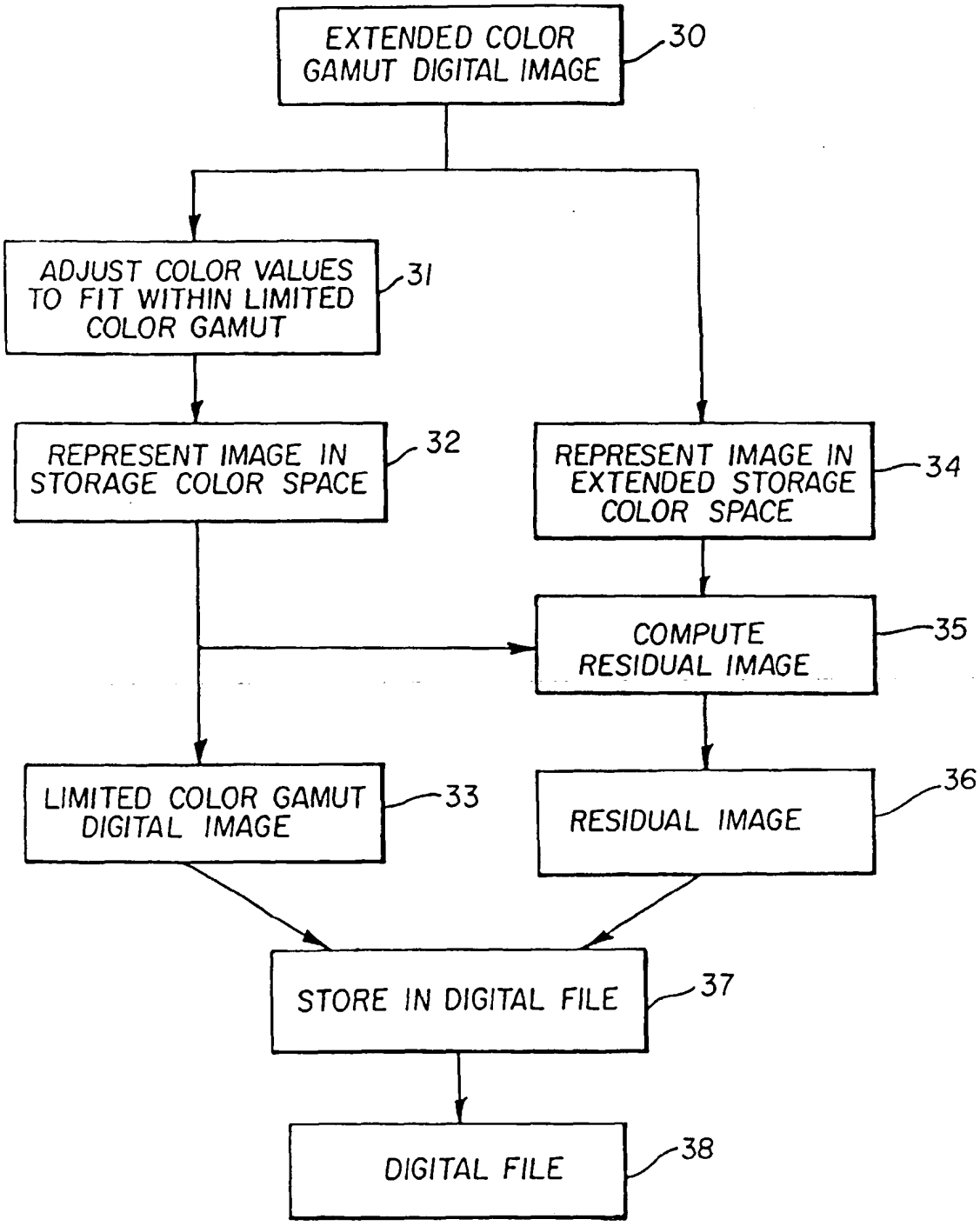

FIG. 3

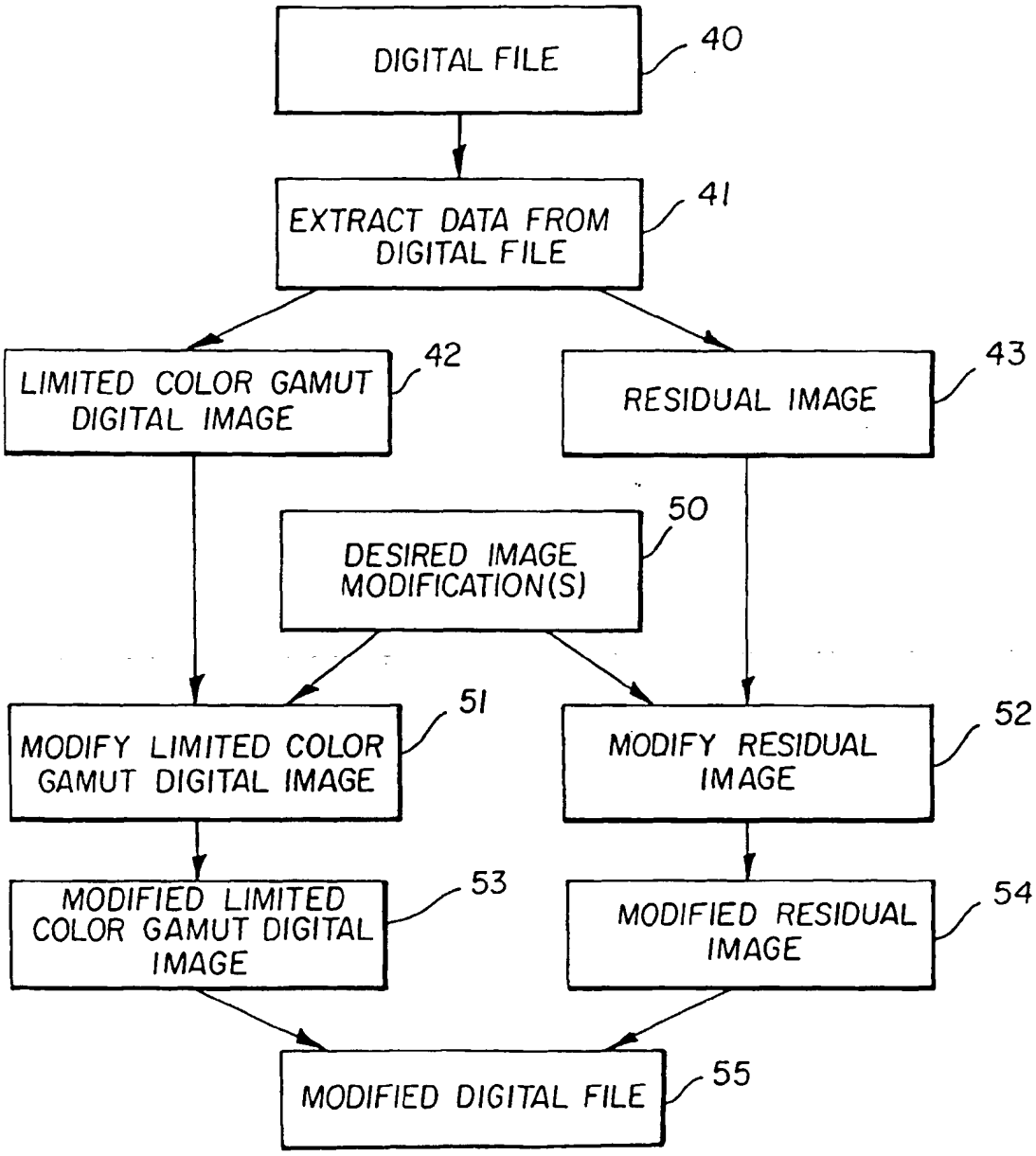

FIG. 5

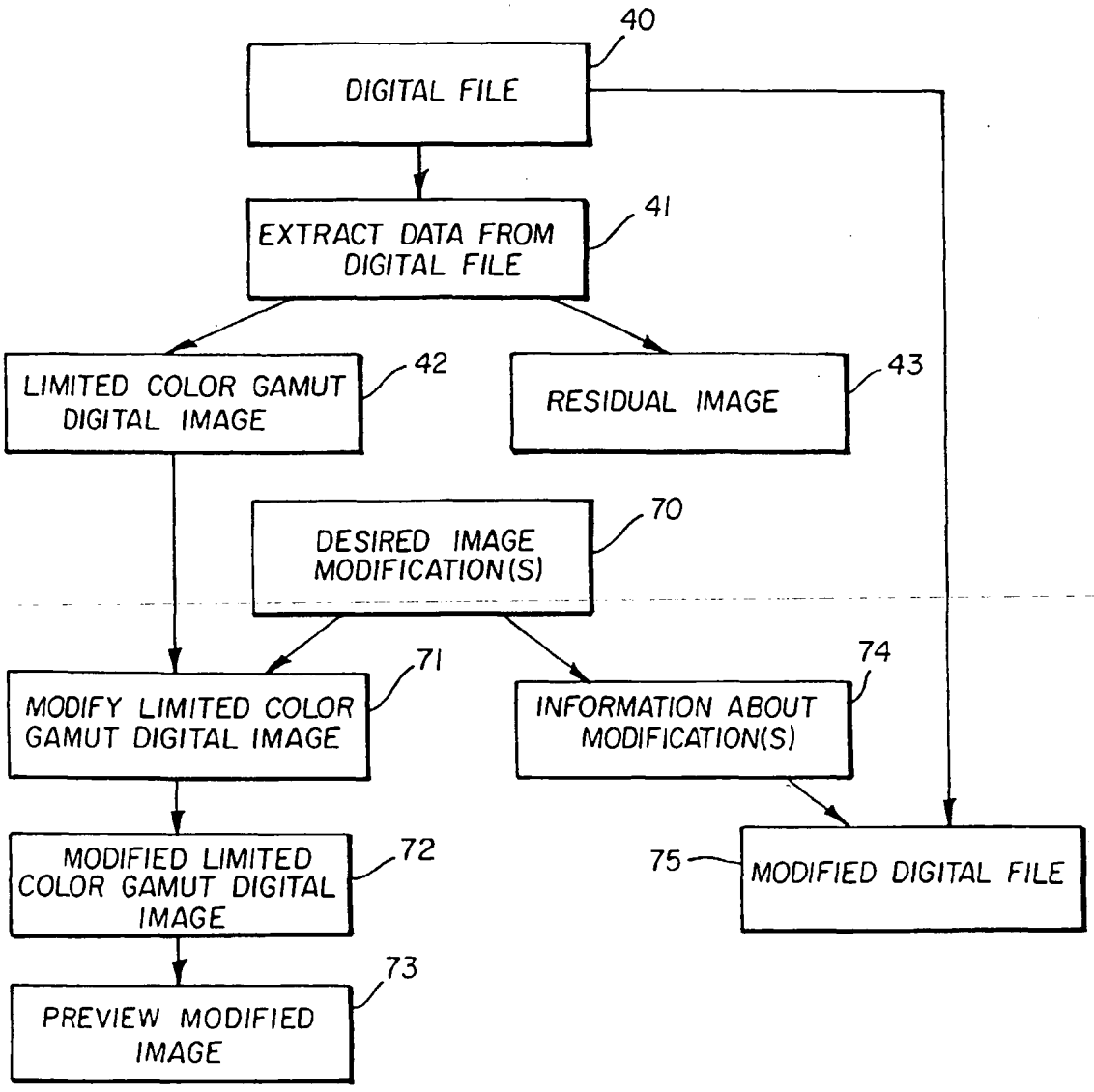
40
DIGITAL FILE
41
EXTRACT DATA FROM DIGITAL FILE
42
LIMITED COLOR GAMUT DIGITAL IMAGE
43
RESIDUAL IMAGE
70
DESIRED IMAGE MODIFICATION(S)
71
MODIFY LIMITED COLOR GAMUT DIGITAL IMAGE
74
INFORMATION ABOUT MODIFICATION(S)
72
MODIFIED LIMITED COLOR GAMUT DIGITAL IMAGE
73
PREVIEW MODIFIED IMAGE
75
MODIFIED DIGITAL FILE

FIG. 7

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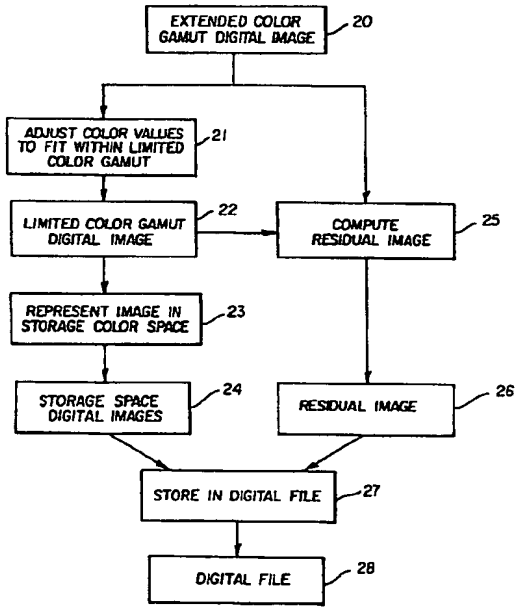

FIG. 2

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